

SPACE
TELESCOPE
SCIENCE
INSTITUTE

PREPRINT SERIES

No.300

NOVAE AS DISTANCE INDICATORS

Holland C. Ford

Robin Ciardullo

(NASA-CR-186278) NOVAE AS DISTANCE
INDICATORS (Space Telescope Science Inst.)
18 p CSCL 03A

N91-11605

Unclas

G3/89 0257149

LIBRARY COPY

SEP 1 1988

LANGLEY RESEARCH CENTER
LIBRARY NACA
HAMPTON, VIRGINIA

August 1988

SPACE TELESCOPE SCIENCE INSTITUTE
3700 San Martin Drive Baltimore, MD 21218

NOVAE AS DISTANCE INDICATORS

Holland C. Ford

Department of Astronomy

University of Michigan, Ann Arbor, MI 48109

Space Telescope Science Institute

Homewood Campus, Baltimore, MD 21218

Robin Ciardullo

Kitt Peak National Observatory, Tucson, AZ 85726

Space Telescope Science Institute

Homewood Campus, Baltimore, MD 21218

To be published in the proceedings of

Extragalactic Distance Scale Symposium, 1989

percent.

ABSTRACT

Nova shells are characteristically prolate with equatorial bands and polar caps. Failure to account for the geometry can lead to large errors in expansion parallaxes for individual novae. When simple prescriptions are used for deriving expansion parallaxes from an ensemble of randomly oriented prolate spheroids, the average distance will be too small by factors of 10% to 15%. The absolute magnitudes of the novae will be underestimated and the resulting distance scale will be too small by the same factors. If observations of partially resolved nova shells select for large inclinations, the systematic error in the resulting distance scale could easily be 20% to 30%. ~~percent~~ . A

Extinction by dust in the bulge of M31 may broaden and shift the intrinsic distribution of maximum nova magnitudes versus decay rates. We investigated this possibility by projecting Arp's and Rosino's novae onto a composite $B - V$ 6200 Å color map of M31's bulge. Thirty two of the 86 novae projected onto a smooth background with no underlying structure due to the presence of a dust cloud along the line of sight. The distribution of maximum magnitudes versus fade rates for these "unreddened" novae is indistinguishable from the distribution for the entire set of novae. ~~We conclude that novae suffer very little extinction from the filamentary and patchy distribution of dust seen in the bulge of M31.~~ ~~it is concluded~~

Time averaged B and $H\alpha$ nova luminosity functions are potentially powerful new ways to use novae as standard candles. We ~~analyzed our~~ modern CCD observations, and the photographic light curves of M31 novae found during the last 60 years to show that these functions are power laws. Consequently, unless the eruption times for novae are known, the data cannot be used to obtain distances. ~~were analyzed~~

I. INTRODUCTION

The photographic discovery of novae in "spiral nebulae" by Ritchey in 1917 was one of the earliest keys to correctly sizing the Universe. After finding a previously unrecorded star in NGC 6946, Ritchey (1917) searched a series of plates taken in 1909 and found two objects in M31 with nova-type light-curves. Systematic observations over the next two years resulted in the detection of fourteen additional novae in M31. Quoting from Hubble (1936) "Curtis immediately pointed out that the apparent faintness of novae in spirals indicated large distances, averaging at least one hundred times greater than the mean distance of galactic novae".

Novae proved to be good distance indicators because they were bright and easily identifiable. The first distance measurements were made by comparing the mean maximum magnitudes of novae in nearby galaxies to the mean absolute magnitude of galactic novae. In 1945 McLaughlin deduced a relationship between the "duration" of a nova and its absolute magnitude. Eleven years later in a landmark paper Arp (1956) used the light

curves of 24 novae in M31 to quantify the relationship between absolute magnitude and the time to fade 2 magnitudes from maximum.

Novae continue in good standing as distance indicators because they are bright, easily identifiable, and because their light curves can be used to determine their absolute magnitudes. De Vaucouleurs (1978) lists novae as one of four primary distance indicators, the other three being Cepheids, RR Lyrae and HB stars, and AB Supergiants and Eclipsing binaries. Cohen and Rosenthal (1983; CR) and Cohen (1985) used expansion parallaxes of galactic novae to calibrate the dependence of absolute magnitude on fade rate. Van den Bergh and Pritchett (1986) recently discussed the advantages of novae as distance indicators, and subsequently (Pritchett and van den Bergh 1987; PvdB) used observations of 9 novae in NGC 4472 and NGC 4365 to estimate the distance to the Virgo cluster.

In spite of their good standing, there are problems in calibrating novae as standard candles. Expansion parallaxes, which were suggested by McLaughlin as early as 1942, are in principle an easy and accurate way to measure the distances to galactic novae, and thus calibrate their absolute magnitudes. However, rather than being spherical, nova shells typically have a prolate geometry consisting of polar caps and an equatorial ring. Failure to account for the geometry can lead to large systematic errors in the derived distances.

Payne-Gaposchkin (1957) was one of the first authors to suggest using observations of novae in M31 and M33 (and the Magellanic Clouds) to calibrate novae relative to Cepheids and RR Lyrae stars. Although this approach demotes novae from primary to secondary standard candles, it enables us to extend the Cepheid and RR Lyrae calibration to early type galaxies which do not have Population I Cepheids or are too distant for detecting RR Lyrae stars. A potential problem with calibrating novae in M31 is internal extinction in M31's bulge. If extinction is present, it will broaden and shift the magnitude fade-rate calibration.

In the following sections we take a critical look at these problems, and then discuss a new approach, randomly sampled B and H α luminosity functions, for using novae as standard candles.

II. CALIBRATION PROBLEMS AND SELECTION EFFECTS

A) Shell Morphology

We can easily see that a nonspherical shell can lead to a systematic error in an expansion parallax by considering an oblate spheroid. The maximum projected dimension of the spheroid always will be the major axis, whereas the observed expansion velocity will always be less than or equal to the velocity in the equatorial plane. Consequently, the derived distance will always be less than the true distance. In order to determine whether or not the geometry of nova shells should be included in the derivation of expansion parallaxes, we must first establish the nature of the geometry.

As early as 1941 Payne-Gaposchkin had recognized that the four-peaked emission line profiles seen in some novae showed that the shells are not spherically symmetrical. This conclusion is confirmed by detailed studies of individual novae. V 603 Aql (nova Aql 1918), a typical fast nova, is a spectroscopic binary with a period of 3 hours and 20 minutes and a very small velocity amplitude, suggesting that the orbital plane is viewed nearly face on. Mustel and Boyarchuk (1970; MB) concluded that V 603 Aql's shell has a central equatorial belt, a pair of tropical/temperate belts, and polar caps at each end of the major axis. The belts and polar caps are caused by large density enhancements relative to other latitudes on the shell. MB's morphologic description was verified by Weaver's (1974) exhaustive analysis of the spectral development of the nova from outburst in 1919 through 1922. Weaver described the shell as a series of "truncated cones" with the axis of the cones inclined by less than a degree to the line of sight. If this is correct, the planes of the equatorial band and the belts are parallel to the plane of the binary.

Weaver did not give a value for the ratio of the equatorial radius to polar axis. Because the shell is seen almost end on, there is no feasible way to determine the ratio of the major axis (the polar axis) to minor axis (the equatorial radius). *Consequently, the shell is "geometrically degenerate"; a parallax cannot be determined from the angular size and expansion velocity.* The only way to derive a parallax is to assume or guess the ratio of the major and minor axes.

MB and Weaver described the morphological development of the slow nova DQ Her as an expanding shell with an equatorial band and two polar caps. The bright equatorial band seen in early photographs has evolved into the three bands seen in Figure 1 and in a picture taken by Williams *et al.* (1978). The preservation of the bands as the nova evolves shows that the shell is prolate. Since DQ Her is an eclipsing binary we are seeing the orbital plane almost edge on. The most physically intuitive geometry (also suggested by Weaver) is one wherein the central equatorial belt coincides with the accretion disk and orbital plane of the binary. The expansion of the shell in the equatorial direction is then slowed by an interaction with the mass-transferring secondary.

MB note that the fast nova T Aur (1891) is an eclipsing binary with a period of 4 hours and 54 minutes. Since the system eclipses it must be nearly edge on, and thus might be expected to have a morphology similar to DQ Her. Baade's 1956 picture of T Aur (*cf.* MB) shows an "oval" with a 1.5/1 axial ratio. From comparison with DQ Her it is reasonable to conclude that the nonspherical shell also is a prolate spheroid with the polar axis perpendicular to the binary's orbital plane.

Based on the spectral development and multiple peaks in the slow (and unique) nova HR Del (1967), Hutchings (1972) modeled the shell as two equatorial rings expanding at 500 km s^{-1} and two polar blobs or caps moving at 200 km s^{-1} . This oblate model was later confirmed by Soderblom's (1976) spatially resolved spectra.

Hutchings (1972) also analyzed the intermediate speed nova FH Ser (1970) and concluded that shortly after outburst the nova was slightly oblate with an equatorial ring and

polar caps and was surrounded by a low density, high velocity spherical shell. Eventually the spherical shell and ring dissipated, leaving only the polar caps, *i.e.*, a prolate geometry. If there are only polar caps, the distance will be give by

$$D = 2 \times V_{obs} \times T \times \tan(i)/\theta$$

where i is the inclination of the line connecting the polar caps to the line of sight, V_{obs} is the observed radial velocity ($V_{obs} = V_{true} \times \cos(i)$), T is the time since outburst, and θ is the angular separation of the polar caps on the sky. *Since we do not know the inclination, we cannot determine D .*

The preceeding discussion is summarized in Table 1. In a nutshell, symmetrical nova shells appear to be composed of equatorial rings and a pair of polar caps, with maximum elongation along the polar direction. The best novae for understanding the geometry are the eclipsing binaries like T Aur and DQ Her where the shell is seen from the equatorial plane.

Table 1. Geometry of Nova Shells

Nova	Type	Morphology	Geometry
V 603 Aql 1918	Fast	Equatorial Rings Polar Caps	Prolate or Oblate
T Aur 1891	Fast	Oval	Prolate
HR Del 1967	Slow	Equatorial Rings Polar Caps	Oblate
DQ Her 1934	Slow	Equatorial Rings Polar Caps	Prolate
FH Ser 1970	Intermediate	Polar Caps	Prolate

B) Distances to Individual Novae

The importance of properly including the geometry of the shell in expansion parallaxes can be illustrated by considering V 603 Aql, FH Ser, DQ Her, and T Aur. As we have seen, V 603 Aql and FH Ser are geometrically degenerate. The uncertainty in the distance to V 603 Aql is equal to the uncertainty in the ratio of the major axis to the minor axis. Since some nova shells may be spherical, whereas other nova shells such as T Aur have a

major to minor axis ratio $a/b = 1.5$, the uncertainty in the distance can be $\sim 50\%$, and is bounded only by our beliefs about the permissible range of expansion velocities for fast novae. Consequently, the errors in the distance could be a factor of 2 or more. In spite of these large uncertainties, the published parallaxes have not included qualifications about their derived distances.

The nearly edge-on, prolate geometry of DQ Her's shell should provide one of the most accurate expansion parallaxes. Nonetheless, published parallaxes range from 320 pc (MB) and 302 pc (CR) to 485 pc (± 50 pc) (Jenner 1978,1988). Figure 1 shows the high spatial resolution image of the shell and the high dispersion $H\alpha$ velocity ellipsoid which Jenner used to model DQ Her. The difference between the data and the model is shown in the right hand panels of Figure 1. The sharpness of the bands and the small degree of tilt in the velocity ellipsoid confirm that the prolate shell is seen nearly edge on. Jenner derived an axial ratio $a/b = 1.4$, an inclination of 87 degrees between the line of sight and the major axis, a maximum expansion velocity (i.e., along the major axis) of 550 km s^{-1} , and a distance of 485 pc. The primary difference between Jenner's and MB's parallax stems from the different minor axis expansion velocities which were used (393 km s^{-1} and 290 km s^{-1} , respectively). The difference between Jenner's and CR's parallax is due again to the assumed tangential expansion velocities (CR used 315 km s^{-1}) and the assignment of the *observed* expansion velocity to the minor axis (Jenner) and the major axis (CR).

CR's distance to T Aur (1320 pc) was derived by assigning the observed expansion velocity to the major axis. Since T Aur is an eclipsing binary (Kraft 1964), the major axis of the shell is most likely nearly perpendicular to the line of sight. If this is correct, the ratio of the true distance to CR's distance could be as large as $a/b = 1.5$.

Based on the preceding discussion, we conclude that the errors in expansion parallaxes to individual novae may be much larger than is generally recognized. In the next section we investigate the question of whether or not the errors average to zero when a large number of randomly oriented shells are observed.

C) Expansion Parallaxes for Randomly Oriented Spheroids

In one of the earliest papers on expansion parallaxes McLaughlin (1945) stated the following. "Involved in these results is the assumption that the velocity of ejection was equal in all directions. We know this is not strictly true, for some of the shells have visibly elliptical cross section. However, we can expect the orientation of ellipsoidal shells to be random relative to the line of sight." McLaughlin assumed that the errors in the parallaxes would average to zero for randomly oriented spheroids. This obviously cannot be true if the shells are oblate, since a parallax based on projected dimensions and the observed radial velocity will always be less than the true parallax. However, the result of observing an ensemble of randomly oriented prolate spheroids is not so obvious, since the derived distance can be too large or too small, depending on the orientation of the spheroid.

We will use two limiting geometries to show that the errors in the parallaxes do not average to zero when observing randomly oriented prolate spheroids. In the first case we simplify the characteristic geometry of novae by assuming a thin equatorial band and two small polar caps. We then use CR's prescription of combining the observed expansion velocity with the maximum angular radius of the shell to derive the "observed distance." In Table 2 we tabulate the ratio of the observed distance to the true distance, $D_{obs}/D_{true} = f(i)$, as a function of the inclination between the line of sight and the major axis of the spheroid.

Table 2. Dependence of Observed Distance on Inclination

Inclination	D_{obs}/D_{true}
$i < \arctan(b/a)$	a/b
$\arctan(b/a) < i < \arctan(a/b)$	$\cot(i)$
$\arctan(a/b) < i$	b/a

The distribution of inclinations will be given by $\sin(i)$. The average ratio of distances will be given by

$$\langle D_{obs}/D_{true} \rangle = \frac{\int_0^{\pi/2} f(i) \sin(i) di}{\int_0^{\pi/2} \sin(i) di}$$

Using $f(i)$ from Table 2, we obtain

$$\langle D_{obs}/D_{true} \rangle = a/b + (1 - a/b) \times \cos(\theta) - (1 - b/a) \times \sin(\theta)$$

where $\theta = \arctan(b/a)$.

The ratio of distances is very flat for values of b/a between 0.3 and 0.7, with a value of ~ 0.90 . Thus, there is a 10% systematic error in the distances and an 0.1 mag error in the absolute magnitudes for the simple case we have considered.

For the second geometry we assume that the shell is a thin prolate spheroid with uniform surface brightness and an axial ratio b/a . The ratio of the observed distance to the true distance is then given by

$$D_{obs}/D_{true} = \sqrt{\frac{a^2 + b^2 \times \tan^2(i)}{b^2 + a^2 \times \tan^2(i)}}$$

Numerical integration of $D_{obs}/D_{true} \times \sin(i)$ for different values of b/a gives the results tabulated in Table 3.

Table 3. Systematic Errors for Randomly Oriented Prolate Spheroides

b/a	$\langle D_{obs}/D_{true} \rangle$
0.0	1.00
0.2	0.88
0.4	0.86
0.6	0.89
0.8	0.94
1.0	1.00

The fact that there is very little difference between the average systematic errors for the two geometries shows that the error is rather insensitive to details of the shell structure.

In both cases the ratio of distances is very flat for values of b/a between 0.3 and 0.7, with a value ranging from ~ 0.86 to ~ 0.90 . Thus, there is a 10% to 14% systematic error in the distances and a 0.10 mag to 0.14 mag error in the absolute magnitudes for these simple cases.

One additional point should be made. When observing partially resolved shells, there may be a preferred selection of novae with large major axis inclinations relative to the line of sight. In this case, the systematic error approaches b/a . We conclude that the systematic errors in the published calibrations of absolute magnitude versus fade rate may be as large as 0.2 mag to 0.3 mag. This effect may explain the fact that Cohen's (1985) nova calibration gives a distance modulus to M31 which is 0.3 magnitudes smaller than the distance modulus derived from RR Lyrae stars (PvdB) and infrared observations of Cepheids (Welch *et al.* 1986), and 0.4 magnitudes smaller than the distance derived from the Population II giant branch (Mould and Kristian 1986).

D) Recommendations for Measuring Expansion Parallaxes

In view of the potential problems in measuring expansion parallaxes, we make the following recommendations.

1) High quality, homogenous, moderate resolution spectra should be obtained systematically during the first two or three years after outburst of novae in the Galaxy and the Magellanic Clouds. The development of the absorption/emission line profiles can then be used to infer the geometry of the shell following the methods used by Hutchings (1972) and Weaver (1974).

2) Eclipsing binaries such as DQ Her and T Aur should receive special attention since the nearly edge on geometry reduces the uncertainty in the expansion parallax. A high resolution, spatially resolved spectrum of T Aur should be obtained in order to improve the parallax of this nova.

3) Expansion parallaxes should be derived by combining spatial and spectral models with high quality spatial/spectral observations.

E) Internal Reddening in M31

Many authors have noted that there is scattered dust throughout the bulge of M31 (Johnson and Hanna 1972; Hodge 1980; Gallagher and Hunter 1981; McElroy 1983; Kent 1983; and Ciardullo *et al.* 1988). Extinction by this dust could in principle account for a large fraction of the width in the distribution of maximum magnitudes versus rates of decline observed in M31 (*cf.* Rosino 1964 and PvdB). We investigated this possibility by converting the nebular coordinates of Arp's and Rosino's novae into standard coordinates and then projecting the positions onto a television image of Ciardullo *et al.*'s (1988) composite $B - \lambda 6200$ color map of M31's bulge. The position of each nova was inspected and the nova was classified as unreddened if it projected onto a smooth background with no underlying structure due to the presence of a dust cloud along the line of sight. Thirty two of the 86 novae which project into the boundaries of the composite picture fall in regions which do not show any evidence for dust. The distribution of maximum magnitudes versus fade rates for these "unreddened" novae is indistinguishable from the distribution for the entire set of novae. Consequently, we conclude that there is very little extinction from the filamentary and patchy distribution of dust seen in the bulge of M31.

The apparent absence of extinction in the magnitudes of novae in the bulge of M31 lends confidence to PvdB's calibration of novae via RR Lyrae stars in M31. The surprising absence of significant extinction can be explained if the dust clouds and filaments are optically thick with a relatively small filling factor. Novae are then either in front of the dust and unobscured, or they are behind the dust and are undetected. The variation in absolute magnitude at a given fade rate which is seen in Arp's and Rosino's light curves may then be due to a combination of observational errors in the zero points of the photographic magnitudes and intrinsic scatter in the characteristics of the outbursts (Shara 1981).

III. TIME AVERAGED NOVA LUMINOSITY FUNCTIONS

One of the biggest, if not the biggest difficulty in using nova light curves for extragalactic distance estimates is logistical rather than scientific. The problem is illustrated by PvdB's heroic observations of novae in the Virgo cluster. With 15 half nights on the Canada-France-Hawaii 3.6-m telescope they were able to detect 8 novae in NGC 4472 and

1 nova in NGC 4365. Five of the novae had maximum B magnitudes fainter than 24.0, and thus were close enough to the limiting magnitude to make determination of their decay times difficult. Between the problems of faintness and incomplete coverage, they were able to measure fade rates for six of the novae. Given the fierce competition for time on large telescopes and the common practice of assigning time to observers in small blocks of whole nights, PvdB's observations will not be easily repeated or surpassed.

On the other hand, observing extragalactic novae *at some phase* of their evolution is much easier. In the broadband B filter, fast novae in Virgo will be detectable for about a week; novae of moderate speed should remain visible for a month. Three novae were detected in three fields on the first night of PvdB's observing run in March. Five novae were detectable in 3 fields on the first night of PvdB's observations in April. Thus, the detection rate will be approximately 1 nova per field for a deep CCD picture of a bright elliptical in Virgo. A large sample of novae will be collected if a series of frames are taken over a time span of years. Taken together, the magnitudes of these novae, observed at random phases, form a time averaged nova luminosity function. Because this type of data is relatively easy to obtain, it is important to see if it can be used to measure distances.

In order to investigate this possibility, we created two time averaged broadband luminosity functions using the observations of M31 novae found in the literature. For the first curve, we inverted and differentiated Arp's (1956) homogeneous set of complete B light curves to create the Δt vs. m relation of each nova. We then found the theoretical $N(m)$ vs. m function by summing these curves. Unfortunately, although this works rather well, Arp only observed 30 novae, and the sample may not be truly representative. However, since the turn of the century, over 200 novae have been discovered in M31—the great majority of which were observed in the B or photographic passband (Alksnis and Sharov 1969; Arp 1956; Ciardullo *et al.* 1987; Duncan 1928; Grubissich and Rosino 1957a,b; Hubble 1929; Rosino 1973; Rosino and Grubissich 1955; Sharov 1972; and Sharov and Alksnis 1969, 1970). We therefore created a second, empirically derived luminosity function by randomly sampling these light curves. Although incompleteness is a major problem for the histogram of historical novae, the two curves agree extremely well. However, as Figure 2 shows, when plotted logarithmically, the relation is a line. Unless the outburst times for a sample of novae are known, broadband observations cannot be used to derive distances.

As discouraging as this result is, it is not necessarily fatal. Observations aimed at detecting novae past maximum light should be performed in the narrow band $H\alpha$ filter, not in B . To see why, we compare the $H\alpha$ and B light curves of Nova Cyg 1975 and a typical nova we recently observed in M31 (Figures 3 and 4). The broadband data for Nova Cyg 1975 is that of Young *et al.* (1976) and Williamon (1977). The $H\alpha$ curve for Nova Cyg 1975 was derived from the spectrophotometric measurements of Ferland, Lambert, and Woodson (1986). The zero point of the $H\alpha$ magnitude scale is referred to Vega, with $m_{H\alpha} = 0$ corresponding to a total flux of 1.5×10^{-7} ergs $\text{cm}^{-2} \text{s}^{-1}$ through a 75 Å filter. All novae begin as continuum sources, but after maximum, the $H\alpha$ emission continues to increase for a period of several days (the precise length of time for this brightening

depends on the speed of the nova). Thereafter, while the continuum is undergoing the phase labeled by McLaughlin (1960) as “early decline”, the $H\alpha$ light fades more slowly, in an exponential decay rate labeled by McLaughlin as “final decline.” As a result, for most of a nova’s life, the flux of photons emitted in a 75 Å $H\alpha$ bandpass is 30% to 60% of that radiated in the entire 1000 Å wide B filter. When a nova is at maximum, it is easy to observe in the broadband filter since it is a continuum source; once past maximum, the high contrast of the emission line over the background galaxy makes it far easier to detect in $H\alpha$. This is true for novae of all classes and speeds, and is especially true for the slowest novae, which may have a 3 mag decay time of well over a year. Therefore, if one wants to detect large numbers of extragalactic novae regardless of their evolution phase, whether for the purposes of studying their underlying population, identifying objects for spectroscopic study, or making distance estimates, the survey should be done in the narrow $H\alpha$ line, rather than with a broadband B filter.

For the past few years, we have been performing such an $H\alpha$ survey in several nearby galaxies, in order to investigate the underlying nova-producing stellar population via the observed nova rate and distribution. As a by-product, we have also been building up an estimate of the $H\alpha$ time averaged luminosity function for novae. Figure 5 displays this relation derived from 35 novae in M31. Unfortunately, once again, the distribution is very suggestive of a power law, thus precluding its use as a distance indicator.

IV. SUMMARY AND CONCLUSIONS

We have shown that nova shells are characteristically prolate with equatorial bands and polar caps. Failure to take the geometry into consideration can lead to large errors in expansion parallaxes for individual novae. When simple prescriptions are used for deriving expansion parallaxes from an ensemble of randomly oriented prolate spheroids, the resulting absolute magnitudes will be underestimated and the distance scale will be too small by factors of 10% to 15%. If observations of partially resolved nova shells select for large inclinations, the systematic error in the resulting distance scale could easily be 20% to 30%. Although we make recommendations on how to avoid systematic errors in expansion parallaxes, we think the better approach is to invest effort in observations of M31 to improve and understand the relationship between maximum magnitude and fade rate, and to tie the absolute magnitudes of novae to RR Lyrae stars and Cepheids.

We investigated extinction in the bulge of M31 by projecting Arp’s and Rosino’s novae onto a composite $B - \lambda 6200$ color map of M31’s bulge. Thirty two of the 86 novae projected onto a smooth background with no underlying structure due to the presence of a dust cloud along the line of sight. The distribution of maximum magnitudes versus fade rates for these “unreddened” novae is indistinguishable from the distribution for the entire set of novae. We conclude that novae suffer very little extinction from the filamentary and patchy distribution of dust seen in the bulge of M31. We think this lends confidence to

efforts aimed at calibrating novae (and planetary nebulae) in the bulge of M31 against other standard candles in M31.

Time averaged B and $H\alpha$ nova luminosity functions are potentially powerful new ways to use novae as standard candles. However, our analysis of a large number of observations show that the time averaged luminosity functions are power laws, and thus have very little utility as standard candles. Nonetheless, $H\alpha$ observations of galaxies will provide an extremely effective way to find novae in order to establish the nova rate and to measure the spatial distribution of novae.

V. ACKNOWLEDGEMENTS

The authors were Visiting Astronomers at Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation. We are grateful to Xiaohui Hui for providing the analytical solution for D_{obs}/D_{true} for a prolate spheroid with uniform surface brightness, and for help in preparing the camera ready manuscript. This work was supported in part by NASA grants NAS 529293 and NAGW-421.

REFERENCES

- Alksnis, A.K., and Sharov, A.S. 1969, *Astron. Tsirk.*, **507**, 1.
Arp, H.C. 1956, *A. J.*, **61**, 15.
Ciardullo, R., Ford, H.C., Neill, J.D., Jacoby, G.H., and Shafter, A.W. 1987, *Ap. J.*, **318**, 520.
Ciardullo, R., Rubin, V.C., Jacoby, G.H., Ford, H.C., and Ford, W.K. Jr. 1988, *A. J.*, **95**, 438.
Ciardullo, R., Jacoby, G.H., Ford, H.C., and Neill, J.D. 1988b, *Ap. J.*, (*submitted for publication*).
Cohen, J.G., and Rosenthal, A.J. 1983, *Ap. J.*, **268**, 689.
Cohen, J.G. 1985, *Ap. J.*, **292**, 90.
de Vaucouleurs, G. 1978, *Ap. J.*, **223**, 351.
Duncan, J.C. 1928, *Pub. A.S.P.*, **40**, 347.
Ferland, G.J., Lambert, D.L., and Woodman, J.H. 1986, *Ap. J. Suppl.*, **60**, 375.
Gallagher, J.S., and Hunter, D.A. 1981, *A. J.*, **86**, 1312.
Grubissich, C., and Rosino, L. 1957a, *Con. Asiago* no. 77.
Grubissich, C., and Rosino, L. 1957b, *Con. Asiago* no. 93.
Hodge, P.W. *A. J.*, **85**, 376.
Hubble, E. 1929, *Ap. J.*, **69**, 103.

- Hubble, E. 1936, *The Realm of the Nebulae* (New Haven and London: Yale University Press).
- Hutchings, J.B. 1972, *M.N.R.A.S.*, **158**, 177.
- Jenner, D.C. 1978, *B.A.A.S.*, **10**, 427.
- Jenner, D.C. 1988, private communication
- Johnson, H.M., and Hanna, M.M. 1972, *Ap. J. (Letters)*, **174**, L71.
- Kent, S.M. 1983, *Ap. J.*, **266**, 562.
- McElroy, D.B. 1983, *Ap. J.*, **270**, 485.
- McLaughlin, D.B. 1942, *Pop. Astr.* **50**, 233.
- McLaughlin, D.B. 1945, *Pub. A.S.P.*, **57**, 69.
- Mould, J. and Kristian, J. 1986, *Ap. J.*, **305**, 591.
- Mustel, E.R., and Boyarchuk, A.A. 1970, *Astrophys. Space Sci.* **6**, 183.
- Payne-Gaposchkin, C. 1941, in *XIII Colloq. Int. Astrophys., Novae and White Dwarfs*, A.J. Shaler ed., p.69.
- Payne-Gaposchkin, C. 1957, *The Galactic Novae* (New York: Dover).
- Pritchett, C.J., and van den Bergh, S. 1987, *Ap. J.*, **318**, 507.
- Ritchey, 1917, *Pub. A.S.P.*, **29**, 210.
- Rosino, L. 1964, *Ann. Astrophys.* **27**, 498.
- Rosino, L. 1973, *Astr. Ap. Suppl.*, **9**, 347.
- Rosino, L., and Grubissich, C., 1955, *Con. Asiago* no. 68.
- Shara, M.M. 1981, *Ap. J.*, **243**, 926.
- Sharov, A.S. 1972, *Soviet Ast.*, **15**, 1001.
- Sharov, A.S., and Alksnis, A.K. 1969, *Astron. Tsirk.*, **514**, 1.
- Sharov, A.S., and Alksnis, A.K. 1970, *Astron. Tsirk.*, **560**, 1.
- Soderblom, D. 1976, *Pub. A.S.P.*, **88**, 517.
- van den Bergh, S., and Pritchett, C.J. 1986, *Pub. A.S.P.*, **98**, 110.
- Weaver, H. 1974, in *Highlights of Astronomy, Vol. 3* G. Contopoulos ed. (Dordrecht: D. Reidel Publishing Co.), p. 509.
- Welch, D.L., McAlary, C.W., McLaren, R.A., and Madore, B.F. 1986, *Ap. J.*, **305**, 583.
- Williamon, R.M. 1977, *Pub. A.S.P.*, **89**, 44.
- Williams, R.E., Woolf, N.J., Hege, K., Moore, R.L., and Kopriva, D.A. 1978, *Ap. J.*, **224**, 171.
- Young, P.J., Corwin, H.G., Bryan, J., and de Vaucouleurs, G. 1976, *Ap. J.*, **209**, 882.

FIGURE CAPTIONS

Figure. 1 The top left hand panel shows an $H\alpha + [N II]$ image of DQ Her taken at the prime focus of the Shane 3-m telescope using a single stage Westinghouse image intensifier; the lower left hand panel shows an $H\alpha$ spectrogram taken at the Coude focus of the Shane 3-m telescope using a single stage ITT image intensifier. The two middle panels show Jenner's (1978) model which best fit the observations. The model was used to derive the distance given in the text. The right hand panels show the difference between the model and the observations.

Figure 2 The time averaged M31 nova B luminosity function derived from historical novae.

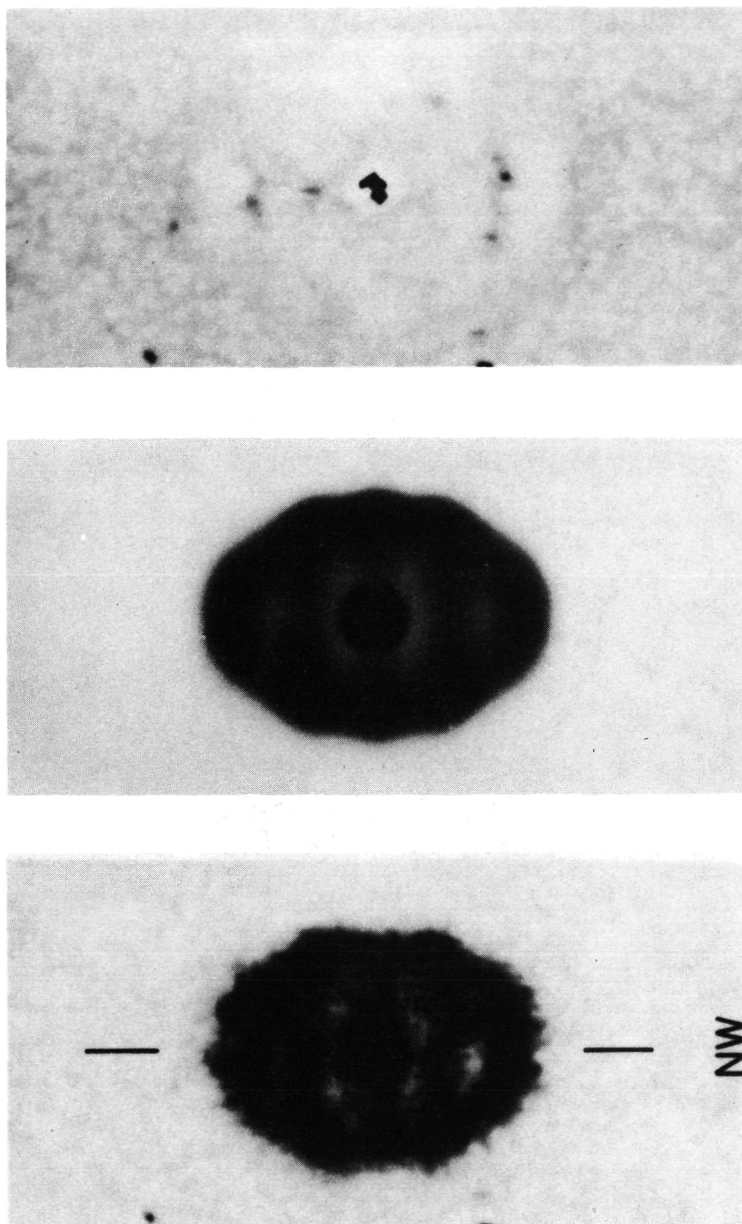
Figure 3 The $H\alpha$ and B light curves for the first month of Nova Cyg 1975. Note that the $H\alpha$ flux continues to rise after the maximum in B , and remains brighter than B as the nova fades.

Figure 4 The B and $H\alpha$ light curves for a typical nova in M31 (CFJN 31). This characteristic light curve shows that shortly after outburst the nova is much more easily detected in $H\alpha$ than in B .

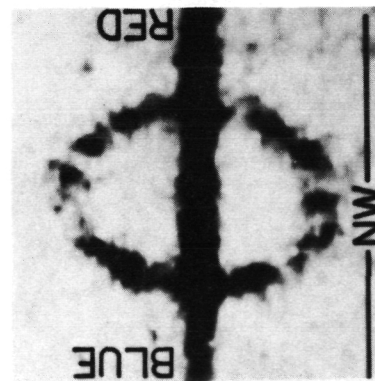
Figure 5 The time averaged M31 nova $H\alpha$ luminosity function derived from modern CCD observations of M31.

NOVA DQ HERCULIS 1934 AT $H\alpha$ $\lambda 6563$

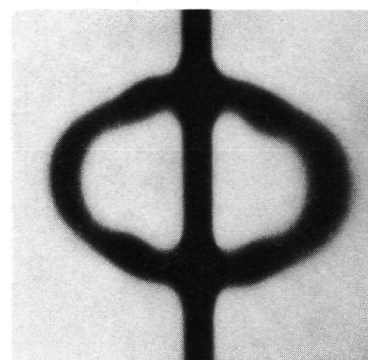
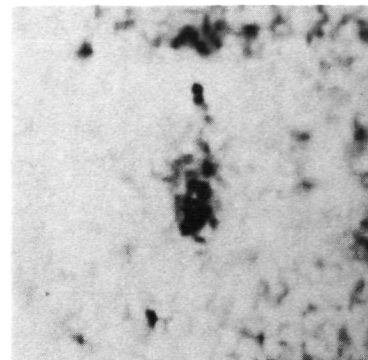
MONOCHROMATIC PICTURE



MAJOR AXIS
SPECTROGRAM



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



DATA - MODEL

MODEL

DATA

Figure 1.

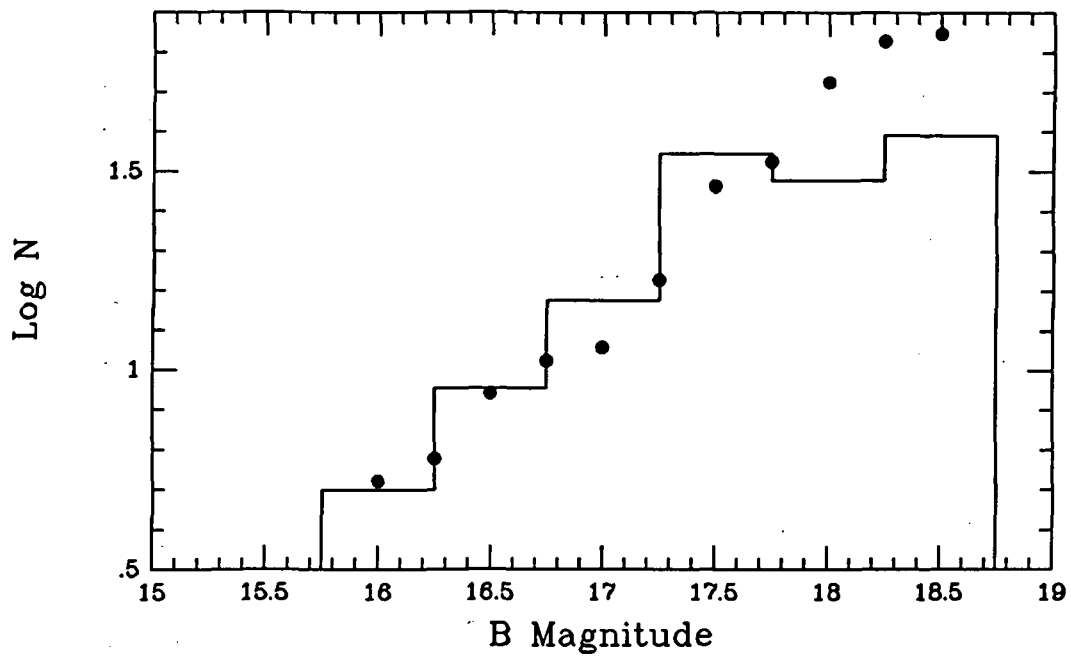


Figure 2.

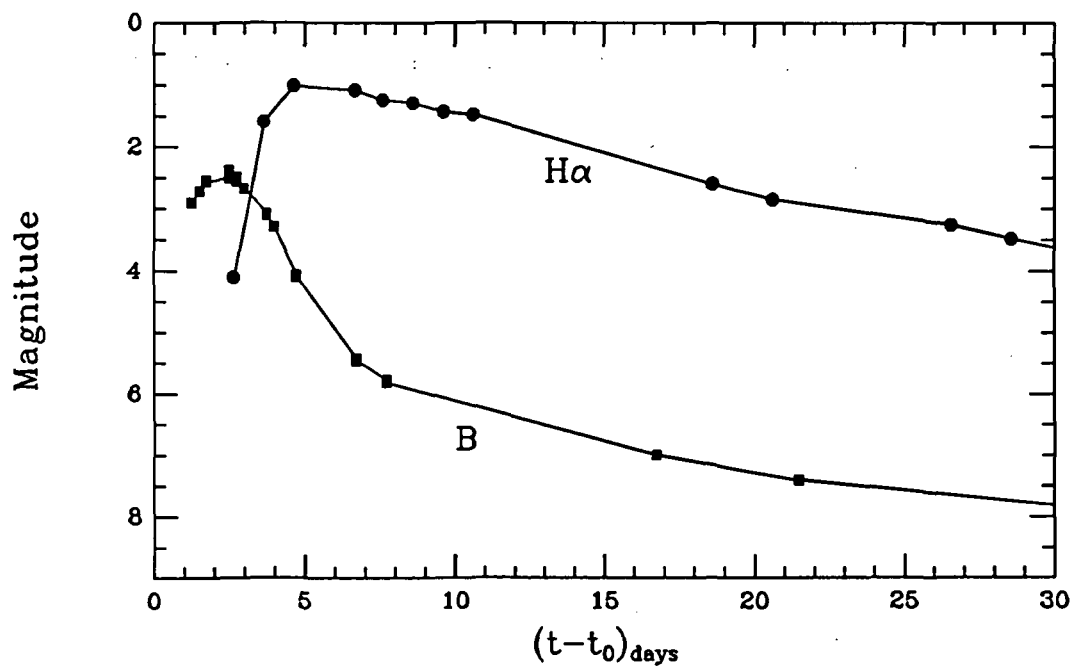


Figure 3.

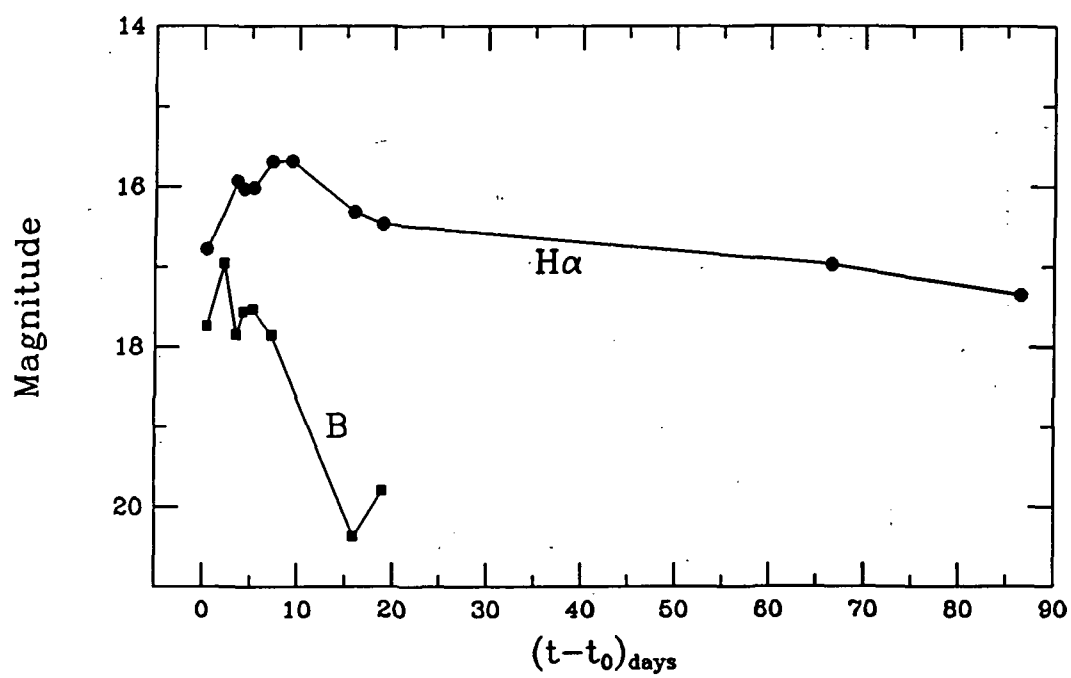


Figure 4.

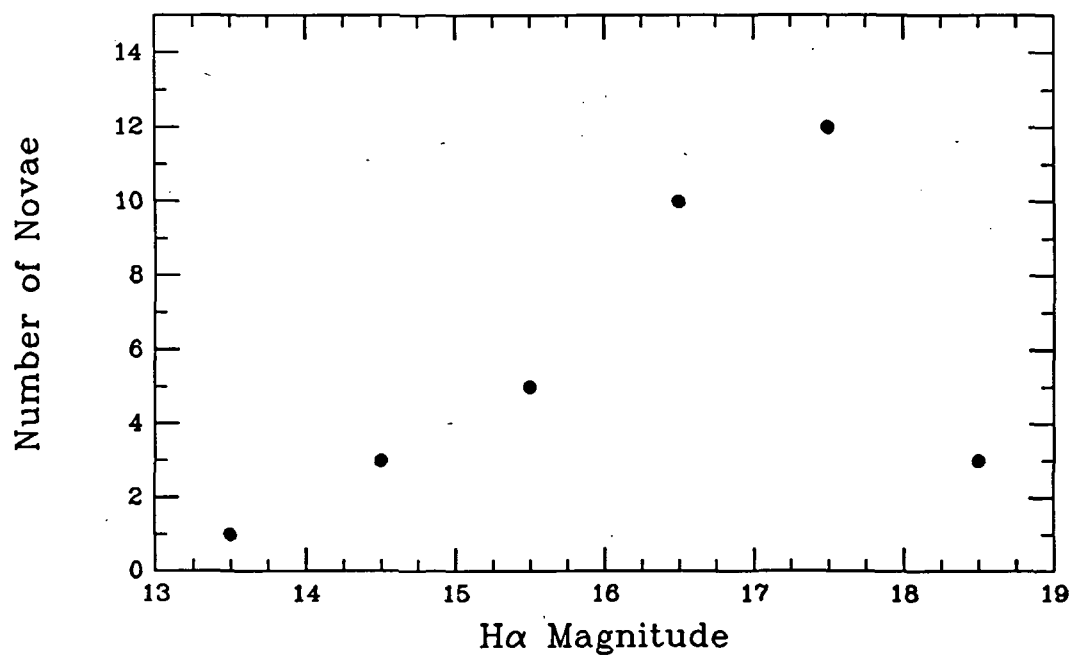


Figure 5.